U.S. ARMY COMBAT CAPABILITIES DEVELOPMENT COMMAND – ARMY RESEARCH LABORATORY

Materials and Manufacturing Overview
HTMDEC Applicant's Day

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MULTI-DOMAIN OPERATIONS (MDO)

Today US military fights as a large expeditionary force

- **Mass in forward support area**
- **Forces posture forward into theatre**

Adversaries have learned & now have the capability to:

- ***Prevent* US forces from gaining access into theater**
- ***Fix* US forces by limited US maneuver capabilities**
- ***Fracture* our interdependent joint force**

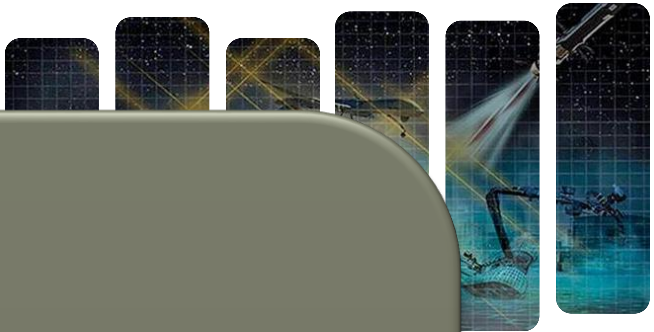
MDO is how the Army will fight tonight, tomorrow, and in the future through:

- ***Convergence* - integration of capabilities across domains, environments, and functions in time and space**
- ***Integration of systems* - focuses on people, process AND the technological solutions required for cross-domain synergy**

ARL enables MDO through research in energetic and propulsion technologies to increase range and lethality in denied environments

Kelly McCoy | October 27, 2017 https://mwi.usma.edu/road-multi-domain-battle-origin-story/

MULTI-DOMAIN OPERATIONS (MDO)



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The Army wants to fight when it needs to fight, where it needs to fight, to have decisive advantage on the battlefield

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ARMY MODERNIZATION PRIORITIES

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	MODERNIZATION PRIORITY	LINES OF EFFORT
1	**Long Range Precision Fires**	Strategic Fires Operational Fires (Precision Strike Missile) Tactical Fires (Extended Range Cannon Arty [ERCA]) 
2	**Next Generation Combat Vehicle**	Optionally Manned Fighting Vehicle (OMFV) Robotic Combat Vehicle (RCV) Mobile Protective Fire Power (MPF) Armored Multi-Purpose Vehicle (AMPV) 
3	**Future Vertical Lift**	Future Attack Recon Aircraft (FARA-CS1) Future Unmanned Aircraft Systems (FUAS) Future Long Range Assault Aircraft (FLRAA-CS3) Modular Open System Approach (MOSA) 
4	**Network (Plus Assured Precision Navigation and Timing)**	Unified Network Common Operating Environment Joint interoperability/Coalition Accessible Command Post Mobility/Survivability Mounted APNT (APNT) Enterprise Enablers (APNT) Situational Awareness (APNT) 
5	**Air and Missile Defense**	Mobile—Short Range Air Defense (M-SHORAD) IFPC – Indirect Fire Protection Capability (Iron Dome) bridging capability LTAMDS – Lower Tier AMD Sensors AIAMD – Army Integrated AMD 
6	**Soldier Lethality (Plus Synthetic Training Environment)**	Next Generation Squad Weapon - Automatic Rifle (NGSW-AR) Next Generation Squad Weapon - Rifle (NGSW-R) Integrated Visual Augmentation System (IVAS [HUD 3.0]) Enhanced Night Vision Goggles – B (ENGV—B) One World Terrain (STE) Virtual Trainers (Air/Ground) (STE) Training Simulation Software (STE) Squad Immersive Trainer (STE) Training Management Tools (STE) 

ARMY MODERNIZATION PRIORITIES

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2	N V		
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Modernization Priorities / CFTs were selected to address gaps in capabilities determined by warfighting needs

DEVCOM ARL/WMRD - LRPF, NGCV, AND SL

Soldier Lethality

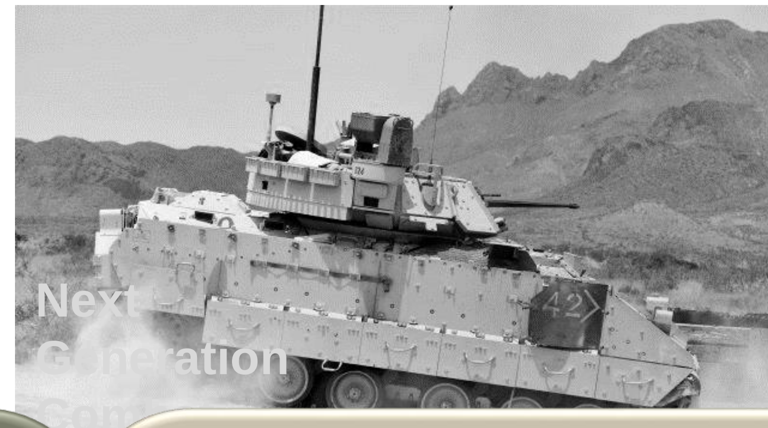
DEVCOM ARL/WMRD - LRPF, NGCV, AND SL

LRPF has:

- High temperature materials
- Advanced structural materials
- Joining techniques
- Energetics
- Aerodynamics
- Interior ballistics

and more….

DEVCOM ARL/WMRD - LRPF, NGCV, AND SL



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- Advanced structural materials
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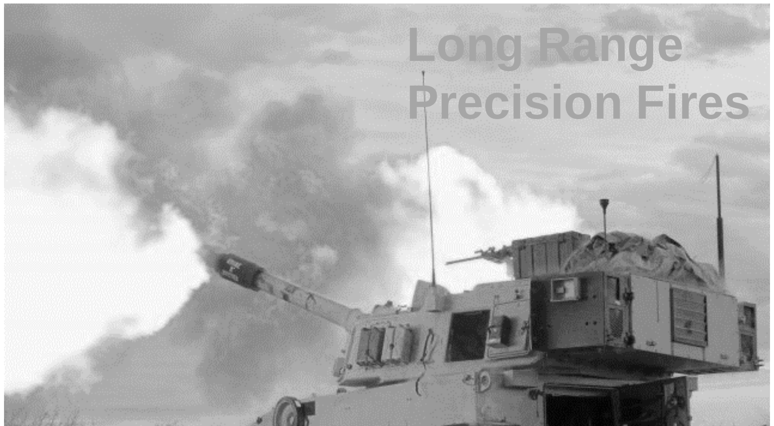
- Aerodynamics
- Interior ballistics

and more….

Fresconi discussed LRDCE ERP; Robinette discussed SAMM ERP

Delivering next generation munitions with higher velocity and better lethality

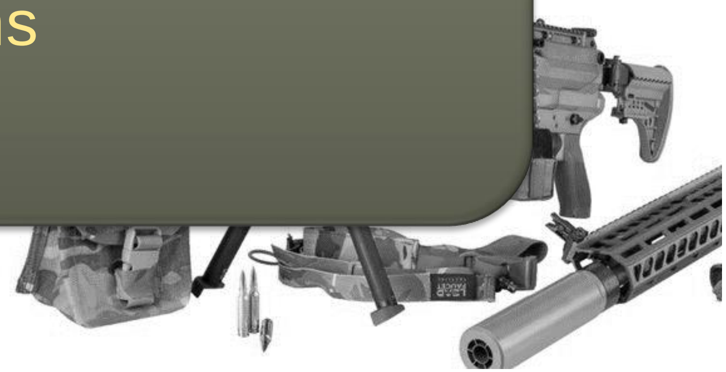
DEVCOM ARL/WMRD - LRPF, NGCV, AND SL



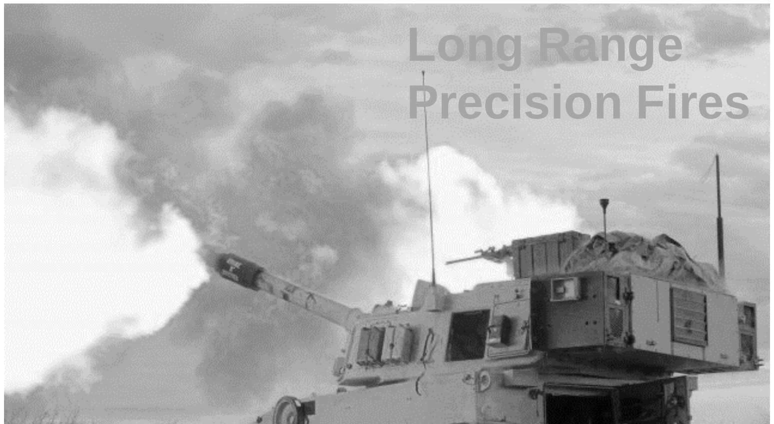
NGCV has:

- Structural materials
- Armor packages
- Coating systems

and more….



DEVCOM ARL/WMRD - LRPF, NGCV, AND SL



NGCV has:

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and more….

Challenges include:

- Multi-faceted structural material optimization (modulus, strength, joinability, corrosion)
- Optimize ballistic materials for use in systems

DEVCOM ARL/WMRD - LRPF, NGCV, AND SL

SL has:

- Ceramics for body armor
- Composites for helmets
- Weapon systems

and more….

Soldier Lethality

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Hoppel discussed PSPDET ERP

Delivering next generation armor and weapons

Soldier Lethality

TERMINAL BALLISTICS

- **A motivational example: terminal ballistics**
  - Historical core competency for ARL – we “own” it
  - Self-inflicted “back and forth” means continual evolution is needed
  - “Mechanics” needs drive “materials”… and vice versa

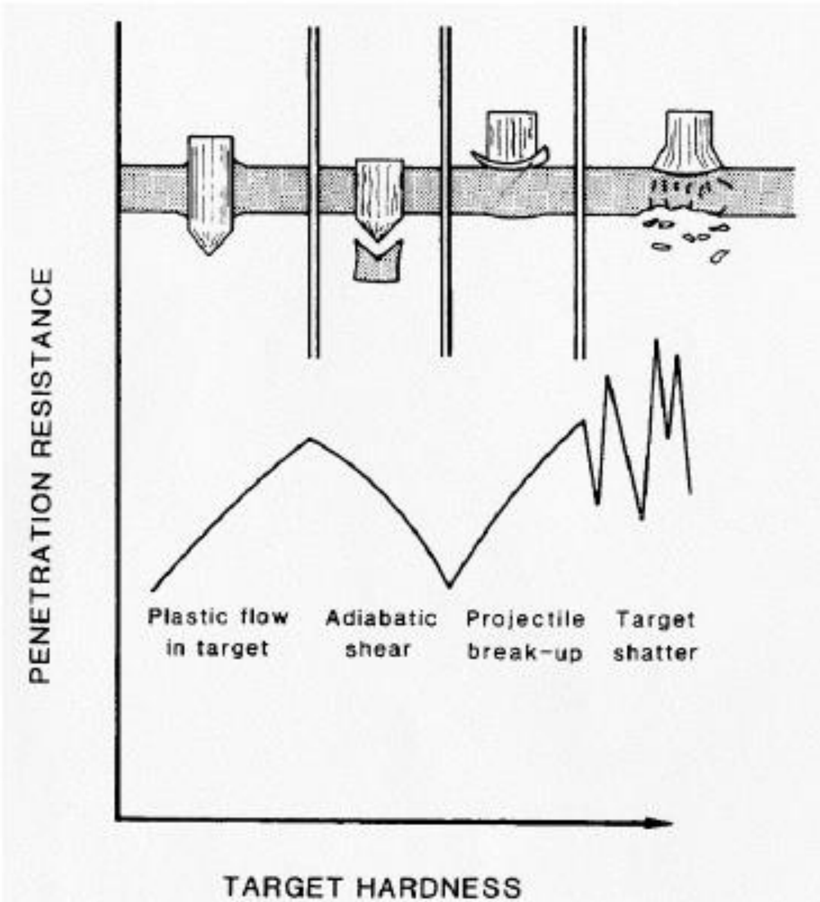
- **Some basic background (bear with me…)**
  - Typical “low” velocity threats are from 0.5 – 1.5 km / s
  - “Interaction time” is 50 to 500 microseconds

  - Example: 0.22” caliber steel L/D=3 cylinder at 1 km/s
    - Energy is 1613 J – a baseball at 330 mph
    - If you are going to stop it within 2 inches, you only have 50μs (power = 31.8 MW)

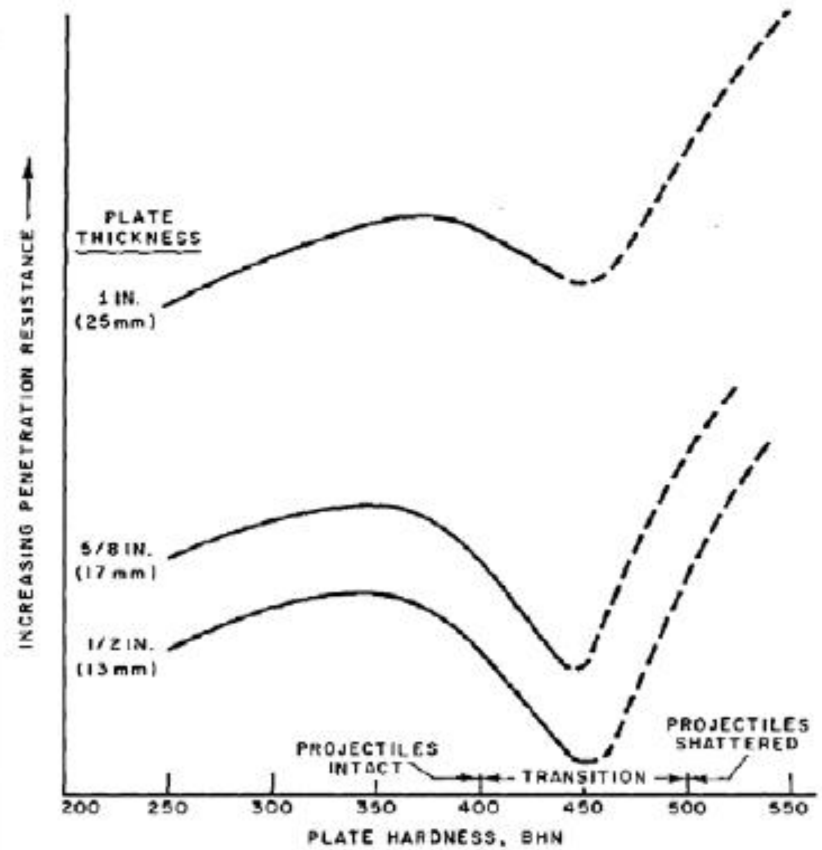
  - Different materials dissipate/redirect energy in different ways
    - Metals have plastic deformation, along with full-plate bending
    - Ceramics use high wave speeds to “spread the load” if you can mitigate cracking
    - Composites use large deformations to engage many high modulus fibers
    - Penetrator materials matter too!

TB EXAMPLE

Penetration of steel as a function of hardness



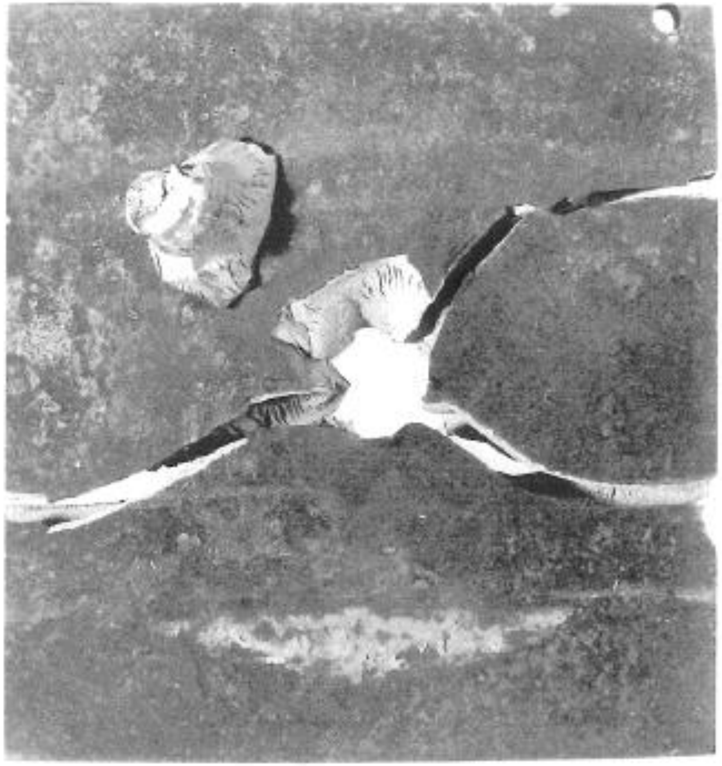
(Woodward, 1988)



(Manganello and Abbott, 1972)

TB EXAMPLE (CONT.)

- **Impact of steel leads to multiple failure mechanisms**
- **.30 cal AP M2 projectile versus hard steel**
  - Initial formation of shear localization
  - Partial plug leads to breakout via "discing"—brittle fracture to back surface
  - Plate "shatters" via brittle fracture
- **Note that the relative fraction of these failures depends on velocity**
  - Example is close to limit velocity of plate
- **So what?**
  - Multiple failure mechanisms
  - Shear localization driven by plasticity at microscale
  - Brittle fracture can be macroscopic loading *or* flaw-driven
  - Interactions of mechanisms matter



From Woodward and Baldwin, Int. J. Mech. Engng Sci, 1979

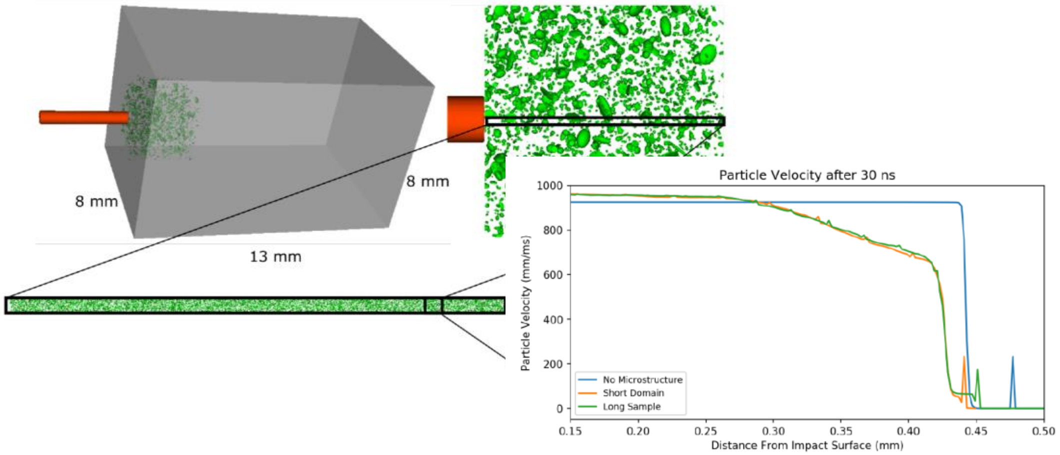
ANOTHER EXAMPLE

- **Boron carbide is a common armor ceramic**
  – Most processing techniques result in abundant graphite inclusions

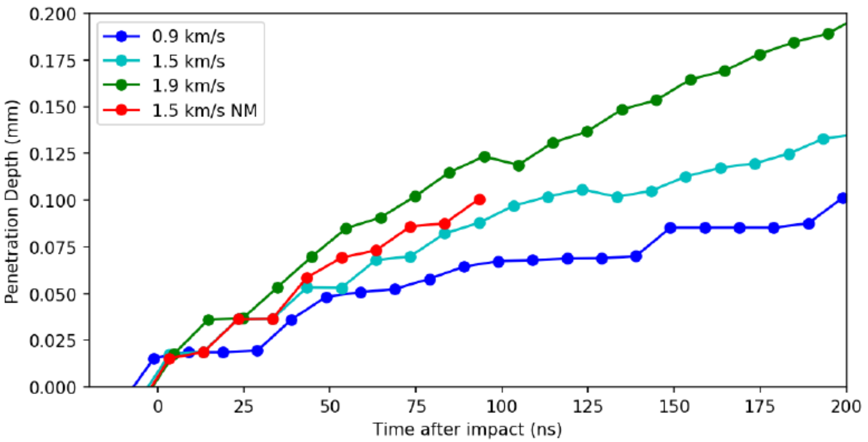
- **We can just average it all out, right?** ***No.***

- **Impact engages multiple length scales due to various kinetics**
  – Joke: which flaws do you activate? *All of them.*
  – Stress waves travel faster than cracks, meaning you can nucleate at many microstructural features

- **We cannot simulate everything**
  – How do you homogenize?
  – Kinetics at various scales
  – What matters?



From Tonge and Schuster, HVIS 2019



SO WHAT? *RESEARCH.*

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- **“Ballistic resistance” is not a material property**
  - Try as we might, we have not found an obvious combination of “properties” that enable us to easily predict performance
  - “Ballistic resistance” for pointy/hard objects and deformable objects is different
  - Mechanics across multiple scales (projectile scale, microstructural scale, scales driven by kinetics) matter

- **Terminal ballistics is one of the few fields where you find the failure envelope and *deliberately* exceed it in practice**
  - Multiple failure nucleation sites, multiple failure modes
  - Kinetics matter

- **So what do we need? Why do we want your help?**
  - The material development cycle is slow, faster would be better (e.g. ICME, MGI…)
  - How do we spot transformative materials in terminal ballistics?
  - How do we “optimize” a ballistic material without just shooting at full scale?
  - Can we probe our prior knowledge and current experiments and simulation capabilities to “suggest” where to go next?

THE WHOLE SCOPE

- **The Army has many material and manufacturing needs**
  - Terminal ballistics fits in with Vargas-Gonzalez and Protection Materials
  - Hypersonics (Blair) has similar complexity: need very high temperature materials for leading edges; need windows and structural materials for high temperatures
  - Lethality (Jannotti) is the other side of the coin for terminal ballistics: dense materials with deformation/failure behavior enabling defeat of protective mechanisms

- **Multi-objective optimization plays a key role**
  - Materials are used in systems with multiple requirements
    - Sure, that ultra-high temperature material is the absolute best at 2000°C, but can it withstand the accelerative loads of launch? Does it have any environmental degradation concerns (can we store this for a decade)? Can we join it with other materials?
  - We have to be able to make these materials, in bulk, in the shape we need, for a reasonable price—in other words, “can you scale?” is part of the initial question, not a “somebody else can do that” afterthought

- **Data science and high throughput experimentation are enablers**
  - If relentless pursuit of a single property would solve our problems… we’d be done.
  - Utilize machine learning techniques from multiple data sources
  - Develop high throughput experimentation to feed both ML and physics-based simulation capabilities

END GOAL

- **ARL is always looking for good research partners**
  – We have:
    - Interesting problems with real-world applications
    - Professional cross-disciplinary staff
  – We need:
    - Experts in individual specialties
    - New ideas and methodologies to tackle difficult problems
    - New employees! (i.e. US citizens flowing through the pipeline)

- **Need to make "progress" faster**
  – Move from "precision" mindset to "decision" mindset
    - Might be great to study one material for 10 years… but at the end, all you have is that **single** material that may or may not solve the performance issue
    - Measure the gradient in the system and keep moving
  – How do we "explore the space" of materials?
    - Structure – property – performance – "multi-objective performance" (i.e. hardness measurements will not do)
    - Use our resources as an aggregate (past work, experiments, computations) to make predictions on what should come next